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U.S. Department  
of Transportation

Deputy Administrator

400 Seventh Street, S.W.  
Washington, D.C. 20590

**National Highway  
Traffic Safety  
Administration**

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MAR 20 1998

NHTSA-98-3585-14

David A. Collins, Esq.  
General Motors Corporation  
Legal Staff  
New Center One Building  
3031 West Grand Boulevard  
P.O. Box 33122  
Detroit, MI 48232

Dear Mr. Collins:

In a letter, dated September 29, 1997, you enclosed a report entitled, "Development of Inspection Technology for NGV Fuel Tanks." This report was prepared pursuant to Project B.7 *Development of Criteria and Methodologies for In-Service Inspections of Gaseous Fuel Pressure Vessels* under the Settlement Agreement between GM and the U.S. Department of Transportation.

When Project B.7 was approved by the National Highway Traffic Safety Administration (NHTSA) on May 15, 1996, NHTSA stated:

... all research performed under [project] . . . B.7 . . . must be submitted to NHTSA in draft. The drafts must then undergo independent review before they are accepted and made public as final.

NHTSA considers the report you submitted to be a draft of the final report. NHTSA provided copies of this draft report to two independent organizations for technical review, Southwest Research Institute in San Antonio, Texas, and Powertech Labs, Inc. in Surrey, British Columbia, Canada. Each of these organizations has completed its technical review of the report and submitted its comments to NHTSA.

The comments that we received regarding the draft report, particularly from Powertech Labs Inc., appear to be substantive and significant. They will need to be addressed. Once GM and its contractor Failure Analysis Associates have had an opportunity to consider these comments carefully,

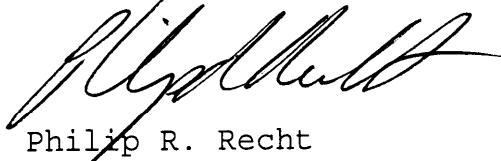
please submit a revised Project B.7 report. With the report, provide a summary of the changes made in response to the comments and, if you believe that certain comments do not need to be addressed, the reasons for this belief.

When the Project B.7 report is resubmitted, if it is determined to be acceptable by the agency, it will be considered as final and placed in the Department of Transportation Dockets, NHTSA-98-3588 and in Docket No. 96-GMRSRCH-GR in NHTSA's Technical Information Services, formerly Technical Reference Library.

Your September 29, 1997 letter and the accompanying draft report will be placed in the Department of Transportation Dockets, NHTSA-98-3585.

Thank you for your cooperation. If you have any questions or need assistance, please call Ms. Heidi L. Coleman, Assistant Chief Counsel for General Law, at (202) 366-1834 or Mr. Lou Brown, of NHTSA's Office of Research and Development at (202) 366-5199.

Sincerely,

A handwritten signature in black ink, appearing to read "Philip R. Recht", written in a cursive style.

Philip R. Recht

Enclosure

# SOUTHWEST RESEARCH INSTITUTE

6220 CULEBRA ROAD . POST OFFICE DRAWER 28510 . SAN ANTONIO, TEXAS, USA 782280510 . (210) 684-5111 . . TELEX 244846

NONDESTRUCTIVE EVALUATION SCIENCE  
AND TECHNOLOGY DIVISION

TELEX: 6866616SWRINDE  
FAX: (210) 6844822

March 11, 1998

Mr. Lou Brown  
USDOT/NHTSA  
NRD-01, Room 6206  
400 7th Street, S.W.  
Washington, DC 20590

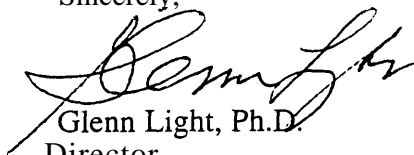
Subject: Review of Report Entitled, "Development of Inspection  
Technology for NGV Fuel Tanks"

Dear Lou:

Here are my comments on the subject report. First, I think the discussion and coverage of acoustic emission was very good, and the authors provided sufficient evidence for their findings. I believe, however, that the authors chose too quickly acoustic emission as the best inspection methodology. Other techniques, such as penetrant, ultrasonics, and eddy current, could also be useful. I did not see any discussion concerning using these other methods.

If you have any questions or comments, please contact me at (210) 522-2218.

Sincerely,



Glenn Light, Ph.D.

Director

Department of Nondestructive Evaluation  
R&D Engineering Applications

/lm



SAN ANTONIO, TEXAS

HOUSTON, TEXAS . DETROIT, MICHIGAN . WASHINGTON, DC

11 March 1998

File: 9964-34

USDOT/NHTSA

400 7th St. SW

Washington, DC 20590



Attention: Lou Brown, NRD-0 1, Room 6206

Dear Mr. Brown,

**RE: REVIEW OF FaAA REPORT - "DEVELOPMENT OF INSPECTION TECHNOLOGY FOR NGV FUEL TANKS"**

**Reference - FaAA-SF-R-97-05-04 Revision 1 (Revised August 1997)**

Just in case the comments I sent to you by e-mail in January were not received.

**OVERVIEW**

1. The **report** contains a useful review of various impact tests involving pressurized composite cylinders.
2. The report summary states that "*...acoustic emission inspection was demonstrated to be a practical method for in-service NGV fuel tank inspection*". However, the acoustic emission data presented does not necessarily support such a conclusion, and the difficulty of utilizing such an inspection procedure in the field was not addressed. The statement made in Section 7.2.3 that "*Additional work is required before a practical inspection method can be developed and qualified*" would **provide** a better sumaation.
3. The report is unaware of the considerable amount of data generated for the Gas Research Institute and Gas Technology Canada regarding the damage tolerance and inspection requirements of various NGV cylinder designs [1-7]. For example, a hoop-wrapped (Type 2) tank will tolerate significantly larger impact damage to the composite wrap compared to Type 3 and Type 4 fully-wrapped designs. Therefore the acoustic emission characteristics of these damaged tanks will also be quite different.



Modal acoustic emission (AE) testing was performed on 3 hoop-wrapped (Type 2) tanks and an all-composite (Type 4) tank, all of which had been intentionally damaged. The modal AE method could not detect damage or impending rupture in 2 of the 4 cylinders tested, despite the fact that the damage was relatively severe.

The AE tests involved overpressuring the 3,600 psig service pressure tanks up to 4,500 and 4,800 psi pressures to obtain signals. It would be difficult in service to achieve such a difference between the tank service pressure and the AE test pressure using available NGV gas pressures. Indeed, considering the inability of modal AE to detect the impending catastrophic rupture of a Type 4 tank, it could be exceedingly dangerous to pneumatically over-pressurize tanks in situ during inspection for flaws. The modal AE technique also relies on the use of higher frequency signals. Unfortunately, these signals may be easily attenuated and therefore more sensors are required to achieve total coverage of a tank, i.e. the cost of testing will escalate. Since an apparent advantage of AE was to perform the testing in situ (i.e. avoid removing the tank from the vehicle), it could prove to be very difficult to install transducers at multiple locations that would provide full coverage.

## **SPECIFIC OBSERVATIONS**

Section 3.3, 4th paragraph - *“...acoustic emission . . . . being the only inspection technique that can inspect the entire **fuel** tank without removing the **tank from the vehicle**”.*

Other potential inspection techniques include acousto-ultrasonics or the use of fiber-optics imbedded in the composite.

Section 6.1, last paragraph - Under the results of Task 1, it cannot be claimed that a “practical” number of AE sensors was used, when in actual fact 4 to 8 sensors were applied to each tank, and the tanks were of relatively short length (many tanks used in NGV service are up to 10 feet long).

Section 6.0 - Very high hydraulic pressures (far in excess of the maximum fill pressures permitted in NGV service) were applied to tanks to generate the AE data - these pressures would not be practical to achieve in-situ on vehicles using gas pressure (nor would it be safe).

Section 6.2.4, 2nd paragraph - It is not explained if the pendulum impact damage was incurred while the tanks were pressurized.

Section 6.3.3, 2nd paragraph - It was observed that *“Just before the failure of the Type 4 tank, a large increase in the number of events per cycle occurred”*. Also in the 3rd paragraph *“The absence of high amplitude, fiber breakage **signals** was somewhat surprising, because catastrophic failure of the tank during fatigue testing must have necessarily **included fiber** breakage”*.

This failure to observe an AE warning that the Type 4 tank (Tank 003) was about to rupture (even when using 7 sensors!) does not elicit confidence in this proposed detection method.

Section 7.1.1, 1st paragraph - *“Fatigue testing of the liner alone and **additional** damage tolerance testing of Type 2 tanks would provide data . . .”*.

Work has already been performed elsewhere on this subject [1,2,7].

Section 7.1.1, 5th paragraph - *“**The** acoustic emission response of Tank 018 could lead to an erroneous conclusion that **little** or no damage was present, when in fact, a **large** slit in the **overwrap** was present and the **overwrap** was **completely** separated **from** the remainder of the tank’*.

This statement illustrates the typical lack of success experienced by researchers trying to apply AE techniques to the inspection of NGV tanks.

Section 7.1.2 - A description of the reasons for the inability of AE to detect impact damage in the Type 4 tank would be useful under this section.

Section 7.2.1, 1st paragraph - *“The presence or absence of damage and damage growth during fatigue was detected in both Type 2 and Type 4 tanks...”*.

This statement is not supported by the statement in Section 7.1.1, 5th paragraph (above), or by the statement in Section 7.2.1, 2nd paragraph (below).

Section 7.2.1, 2nd paragraph - *“Because these signals occurred shortly before catastrophic rupture of the tank, they did not provide **sufficient** early warning of **future** tank failure”. Also, “‘Although fibers necessarily failed during the tank failure process, high **frequency** acoustic emission **signals** characteristic of fiber breakage were not obtained’*.

Therefore, on the Type 4 tank the AE system (a) failed to provide any early warning of impending tank failure, and (b) failed to detect high frequency acoustic emission signals associated with **fibre** breakage.

*“One explanation is that the high frequency **signals** were attenuated by the cracked matrix....”*.

If this is the case, then why use the modal AE technique if the high frequency events are so easily attenuated? Impact damage will always cause heavy matrix damage, especially in Type 4 tanks - if it is true that the matrix damage will attenuate high frequency signals, then the AE technique being proposed may as well be abandoned.

Section 7.2.3, 1st paragraph - *“**The modal** acoustic emission technique used in this project provided the capability to detect and characterize the damage and location of the damage in the composite **overwrap** of the tanks”*.

This statement cannot be justified, given that damage in 2 of the 4 damaged tanks could not be detected. It could just as easily be concluded that AE has little potential, and is inherently difficult to apply to tanks in situ (i.e. multiple sensors must be applied and a high over-pressurization is required). It is stated in

the 5th paragraph of the Summary that *“The characterizations of acoustic emission signals, such as matrix cracking events, were verified by visual examination of the tank”*. It would appear that visual inspection was the only method used by FaAA that was correct in its condition assessment 100% of the time.

*“This correspondence was not always exact, as in the case of Tank 018, in which the large separation of the overwrap was not detected by acoustic emission”*.

It should also be noted that the impending failure of the Type 4 tank was also not detected by modal AE.

## EDITORIAL CHANGES

Throughout the report there should be subheadings for paragraphs which appear immediately after main headings. For example, the paragraphs immediately under “2.0 DAMAGE TOLERANCE OF COMPOSITE STRUCTURES”, should be preceded by a sub heading “2.1 General”, and the subheading “2.1 Damage” should be relabelled “2.2 Damage”, etc.

Similarly, immediately under heading “2.2 Material Influences” there should be a subheading “2.2.1 General”, and the existing subheading “2.2.1 Fiber” should become “2.2.2 Fiber”, etc.

Section 2.2.4 - the word “graphite” should be “glass”.

Section 2.6.1 - 5th paragraph, the references [ 1 1-19] should be corrected to [48-56].

Section 3.1 - references should be provided for the information regarding the 1996 Los Angeles and the 1994 California/Minnesota failures.

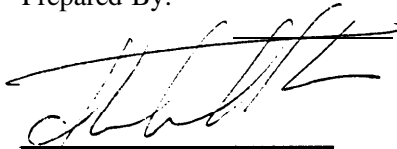
Section 6.0, 2nd paragraph - *“Pressure was also cycled between ambient and a maximum pressure level”*. Instead of “ambient” pressure, perhaps “minimum” pressure, or “zero” pressure or “atmospheric” pressure was the intended wording.

## REFERENCES

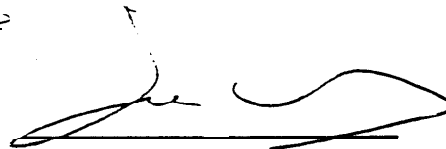
1. G. Bhuyan, “Effects of Composite Damage on the Fatigue Behaviour of the Metal Lined Hoop-Wrapped Cylinders”, Trans. ASME, J. of Pres. Ves. Tech 114, pp. 120-123, 1992
2. Power-tech Labs, “Integrity Assessment of Aluminum Alloy Lined FRP Hoop-Wrapped Cylinders, Gas Technology Canada report NGV200-3.3.4, June 1992.

3. Southwest Research Institute, "Assessment of Design and Durability Issues for Composite NGV Fuel Cylinders", Gas Research Institute report GRI-92/040 1, February 1994.
4. Southwest Research Institute, "Field Study of Composite NGV Fuel Cylinders", Gas Research Institute report GRI-941034 1, September 1994.
5. Powertech Labs, "Environmental Damage of Fibreglass Fully Wrapped NGV Containers Due to Moisture and Road Salt Exposure", Gas Research Institute report GRI-94/0399, October 1994.
6. Powertech Labs, "Resistance of Fibreglass Wrapped NGV Cylinders to Environmental Effects", Gas Research Institute report on IMIS Project No. 04.07.01.0630, January 1995.
7. Power-tech Labs, "Condition Assessment of Glass Fiber Hoop-Wrapped Cylinders Used in NGV Service", Gas Research Institute report GRI-97/0052, July 1997.

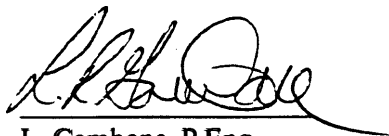
Prepared By:



C. Webster, P.Eng.



J. Wong, P. Eng.



L. Gambone, P.Eng.  
Power-tech Labs Inc.